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Tone-word recognition in Mandarin Chinese

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CHAPTER 3

Form Priming in Tonally Contrasted Word Forms With and Without Lexical-level Phonological Representations in Mandarin Chinese

3.1. Introduction

One of the fundamental brain functions underlying human communication is the recognition of spoken word forms for further syntactic, semantic and pragmatic analyses. Successful word recognition relies on mapping continuous acoustic input onto mental representations of phonology with remarkable speed and accuracy (Vitevitch & Luce, 1998; Dahan & Magnuson, 2006). With respect to the structure of phonological representations, current models have reached a consensus that phonological representations are organised hierarchically with at least two levels: a low level representing sublexical features like phonemes and a high representational level for lexical (word) knowledge (e.g., TRACE model, McClelland & Elman, 1986; Shortlist model, Norris, 1994; Neighborhood Activation Model (NAM), Luce & Pisoni, 1998). Using priming paradigms, studies with behavioural measurements showed that

during the recognition of a spoken word, a prime word sharing high form-similarity with a target word could induce competition at the lexical level (Slowiaczek & Pisoni, 1986; Slowiaczek & Hamburger, 1992; Gaskell & Dumay, 2003; Donselaar, Koster, & Cutler, 2005). However, less is known about the access to phonological representations at the lexical and sublexical levels in tonal languages. The current study used a form-priming paradigm to investigate how phonological representations are accessed when recognising monosyllabic tone words in Mandarin Chinese.

3.1.1. Form priming in spoken word recognition

Form priming is a well-established experimental paradigm which has been used to explore the structure of phonological representations and how those representations are accessed during word recognition (see Zwitserlood, 1996 for a review). In a form priming experiment, a target word form is usually presented after a prime word form. The rationale is that if a prime can activate the mental representation shared by a target, the prime should affect the recognition of the subsequent target. Priming effects can be quantified by reaction times measured in behavioural tasks such as lexical decision and shadowing, namely oral repetition (e.g., Radeau, et al., 1989; Hamburger & Slowiaczek, 1996; Bien, Bölte, & Zwitserlood, 2014).

Two typical priming effects have been identified in spoken word recognition: facilitation and inhibition. Facilitatory priming, as reflected by shorter reaction times relative to a baseline, has been associated with form-based overlaps between a prime and a target (Radeau, Morais, & Segui, 1995; Slowiaczek & Hamburger, 1992; Slowiaczek & Pisoni, 1986). Facilitation has been reliably observed in repetition priming when the prime and the target are identical word forms (Zwitserlood, 1996). Inhibitory priming, indexed by slower reactions compared to a baseline, has been attributed to the inhibition of a primed lexical competitor during the recognition of a phonologically similar target word (Slowiaczek & Pisoni, 1986). Lexical competitors are entries in the mental representation, having, for instance, overlapping phonemes from the word onset. Thus,

given the input of the same portion of a speech signal, these entries compete with each other to be accessed before a word can be identified.

Form-priming effects induced by phonological representations at the lexical level have been investigated by comparing participants' responses to word forms primed by formally related real words or pseudo-words⁴. Studies in both lexical decision and shadowing showed that the high formal similarity between word primes and word targets (e.g., bland-black) did not lead to shorter reaction times than word targets sharing only one initial phoneme (e.g., burnt-black) or no phonemic overlaps (Slowiaczek & Pisoni, 1986; Radeau et al., 1989; Slowiaczek & Hamburger, 1992; Hamburger & Slowiaczek, 1996). The lack of facilitation has been described as lexical interference rather than inhibition because phonologically similar word primes do not always lead to prolonged lexical decision times in target words. This phenomenon has been attributed to a net effect of form-based facilitation and inhibition induced by lexical competition (Slowiaczek & Hamburger, 1992; Wagenmakers, Zeelenburg, Steyvers, Shiffrin, & Raaijmakers, 2004; Lee, 2007). That is, although the phonological overlap can facilitate the processing of the form of target words, the cognitive system still needs to inhibit lexical competitors evoked by prime words. Consequently, lexical interference induces responses without evident facilitatory or inhibitory priming (Hamburger & Slowiaczek, 1996). In contrast, when the prime is a pseudo-word, the recognition of a target word with high phonological similarities (e.g., */blæt/-black) becomes faster (Slowiaczek & Pisoni, 1986; Radeau et al., 1989; Slowiaczek & Hamburger, 1992). Pseudo-words have been described as word forms without lexicalised phonological representations, so the facilitatory priming effect suggests that the re-activation of the same sublexical-level representation can boost the processing at the lexical level. Following this line of reasoning, several studies have successfully revealed that the lexicalisation of pseudo word

⁴ Pseudo-words in studies with European languages are usually novel segment patterns that are meaningless but phonotactically possible.

forms after learning could induce word-like interference (Gaskell & Dumay, 2003; Qiao, Forster, & Witzel, 2009; Qiao & Forster, 2013).

3.1.2. Lexical access in Mandarin Chinese

While existing studies have mainly focused on recognising word forms with similar segments, it remains unclear that how phonological representations are accessed when lexical tones, a suprasegmental cue, play a critical role. Unlike most European languages, tone languages such as Chinese, Vietnamese, and Thai use systematic variations of prosody to differentiate meanings of the same segment. Mandarin Chinese is an ideal linguistic model to study this issue for the following reasons. First, Mandarin is an extreme example of tone languages employing four lexical tones with contrastive pitch contours. Second, the lexical tones in Mandarin are highly lexicalised because each syllable has one lexical tone. A well-known example is that the combinations of a segment /ma/ with the four tones lead to four different words, namely /ma1/ ‘mother’, /ma2/ ‘hemp’, /ma3/ ‘horse’, and /ma4/ ‘curse’.

A number of studies have shown that lexical tones play a comparable role as the segmental cues (e.g., onset and rime) during word processing in Chinese languages (see Schirmer et al., 2005; Malins & Joanisse, 2010; Zhao et al., 2011 for data indicating an equal role; see Cutler & Chen, 1997; Mattys et al., 2005; Yip, 2001; Hu et al., 2012; Sereno & Lee, 2015; Wiener & Turnbull, 2015 for data suggesting a segmental processing primacy). Moreover, both behavioural and neurolinguistic evidence has suggested that the segmental and tonal features of Mandarin words are represented separately in the mental lexicon (Liang & van Heuven, 2004; Liu, et al., 2006; Tong, Francis, & Gandour, 2008). A few studies have also reported evidence that whole-word level representations, namely the lexicalised combinations of segmental and tonal representations, are crucial in the processing of spoken tone words (e.g., Ye & Connine, 1999; Zhao et al., 2011; Malins & Joanisse, 2012; Yue, Bastiaanse, & Alter, 2014). Taking the above-mentioned studies together, it can be concluded that the mental representation in Mandarin Chinese complies with a

general hierarchical organisation: sublexical-level representations store knowledge of consonants, vowels, and lexical tones; meanwhile, lexical-level representations encode the whole-word phonological forms (i.e., the lexicalised combination of segments and tones).

How does a tone word activate the lexical- and sublexical-level representations of phonology during form priming? A few studies have touched upon this question with monosyllabic tonal word forms in Mandarin. Using a lexical decision task, Lee (2007) found that when a monosyllabic Mandarin word was primed by a real-word target with minimal tone contrasts (e.g., /lou3/-/lou2/) with an ISI of 250 ms, the response latency to the target word was not different from the baseline. This result was comparable to an earlier lexical decision study with minimal stress pairs. Like lexical tone, stress is another type of suprasegmental cue to distinguish segmental meanings. Cutler and Otake (1999, Experiment 3) used Japanese words to create prime-target pairs with minimal stress-pattern contrasts (e.g., haSHI ‘chopsticks’ and HAsHI ‘bridge’, in which a stressed syllable is noted with capital letters). They found no difference between the reaction times in targets preceded by primes contrasting in the stress pattern and those in targets primed by phonologically unrelated words. The authors of these studies interpreted their results as an indication of immediate employment of suprasegmental cues to constrain word processing to rule out the primed lexical representations that would compete with the target word. Thus, the recognition of target words primed by segmentally overlapping words was similar to those primed with phonologically unrelated words. This lexical-constraint interpretation is almost equal to the claim that spoken words only contrasting in suprasegmental features are treated as totally different words in the mental lexicon because only in such a situation could the target words not possibly be influenced by the prime’s formal similarity.

Although the lexical-constraining idea could provide an account for priming with minimal tone pairs of words as in Lee (2007), it does not explain other priming results. For example, in a recent study of lexical decision with monosyllabic Mandarin words, Sereno and Lee (2015)

found a fragile facilitation effect in minimal tone pairs⁵ (e.g., /ru3/-/ru4/) and consistent inhibition effects in minimal segment pairs (e.g., onset contrast /pu4/-/ru4/; rime contrast /re4/-/ru4/). If lexical-constraining efficiency is the mechanism to resolve the influence of primes on phonologically similar targets, Sereno and Lee's results imply that segmental cues were less effectively used than suprasegmental cues to rule out lexical competitors. However, such implication of a 'suprasegmental cue primacy' is not in favour of most experimental observations and is less practical for tone-word recognition, in that most existing studies found evidence of either segmental primacy or an equal role of the two types of cues (e.g., Schirmer et al., 2005; Wiener & Turbull, 2015).

Alternatively, a more realistic interpretation might be that the seemingly non-primed responses are a consequence of lexical interference, as documented in early literature which found no facilitatory priming between segmentally similar words in English (e.g., Slowiaczek & Hamburger, 1992; Hamburger & Slowiaczek, 1996). That is, the lack of facilitation is a net effect of form-based facilitation and lexical competition-triggered inhibition. According to this view, the absence of priming effects in minimal tone/stress pairs (Lee, 2007; Cutler & Otaka, 1999) can be explained as follows: the overlapping segment may facilitate the processing of the sublexical features of the targets, but the inhibitory priming at the lexical level balances out the facilitation. This interpretation could somehow reconcile the facilitatory priming effects in minimal tone-pairs reported in Sereno and Lee (2015) and in an early Cantonese study by Yip (2001).

To disentangle the tone word priming issue, further experiments need to be implemented to overcome the limitations in previous studies. First, it was surprising that both Lee (2007) and Sereno and Lee (2015) did not report whether they had normalised their word form recordings. If no sound normalisation was performed, participants might have heard auditory stimuli with varying sound quality, duration, and intensity. This

⁵ Minimal tone pairs are prime-target pairs contrasting only in tones.

limitation may have masked the true picture of form priming in tonal word forms. Second, although they claimed to use the same protocol as Lee (2007), Sereno and Lee reported response latencies that were approximately 300 ms shorter than those in Lee (2007). This quite striking difference might imply that Sereno and Lee (2014) did not measure reaction times in the same way Lee (2007) did. Another possible explanation is that the participants in both studies might not represent the same population, which could weaken the generality of the findings in the two studies. Third, despite the fact that Sereno and Lee matched the number of the four types of tones in the targets, they did not control for the number of homophonic words as Lee (2007) did. Lastly, since pseudo-words were only used as fillers, the best tool to detect sublexical processing had been overlooked (Slowiaczek & Pisoni, 1986, Radeau et al., 1989; Wagenmakers et al., 2004). That is, if interference is a net effect of form-based priming and lexical inhibition, pseudo-word primes should facilitate the processing of target words with minimal phonological contrasts (e.g., phonemes or tones).

3.1.3. The present study

Our study aimed to explore how phonological representations at lexical and sublexical levels are accessed in the form priming of tone words. The current study first sought to replicate Lee's (2007) study to confirm the priming patterns in identical word pairs and minimal tone pairs. Then, to approach the priming effect at the sublexical level, we took advantage of pseudo-words which share common segments with target words but carry different tones, referred to as tone-manipulated pseudo-words. These pseudo-words were phonotactically plausible but without meaning, created by combining a legal segment pattern with a lexical tone in Mandarin Chinese (e.g., */se2/ from /se/ + Tone2). Therefore, this kind of pseudo-word had only sublexical representations without lexical-level entries in the mental lexicon of Mandarin speakers. To study form priming effects at sublexical processing levels, we produced 'prime-target' pairs by pairing pseudo-word targets with segmentally overlapping real and pseudo-word primes.

For real-word targets, we expected no facilitation in the priming condition with tonally contrasted real words, in line with previous experimental findings (Lee, 2007). Moreover, if the lack of facilitation is a result of lexical interference (Slowiaczek & Hamburger, 1992), form-based facilitatory priming could be expected when target words are primed by pseudo-words with minimal tone contrasts due to the absence of entries at the lexical level.

It was difficult to predict the outcome in pseudo-word targets due to limited observation of tonal pseudo-words in form priming. Lexical decision has been assumed to reflect lexicon-based cognitive activities (Balota & Chumbley, 1984). However, due to the lack of lexical-level representations, pseudo-words can only access low-level phonological representations. That is, the priming effect on pseudo-words could only be induced via processing at the sublexical level. Since form-based facilitation has been considered as a sublexical effect, we tentatively predicted that the processing of pseudo-word targets can be facilitated by either pseudo-word or real-word primes with minimal tone contrasts.

3.2. Method

3.2.1. Participants

88 students and staff of Northeast Petroleum University at Daqing, China voluntarily participated in the current experiment (female: 50; mean age = 21, $SD = 3.5$). They were selected to take part in the current study according to a questionnaire issued before the experiment, in which they all reported Mandarin Chinese as their native language, no long-term exposure to other dialects of Chinese⁶, and no history of auditory diseases or speech disorders.

⁶ Since the pseudo-words can be meaningful in other dialects of Chinese (e.g., */na1/ means ‘you’ in *Lanzhou* dialect and ‘take’ in *Xuzhou* dialect), we only included participants with Mandarin as their only native language.

3.2.2. Materials

We first selected 35 monosyllabic Mandarin Chinese real words and generated 35 pseudo-words as targets. For each target, we constructed five types of prime-target pairs. A real-word target was paired with: 1) an RSTR prime (an identical real word that shared the same segment and lexical tone with the real-word target, e.g., /lun4/-/lun4/); 2) an RSR prime (a real word that shared the same segment with the target, e.g., /lun2/-/lun4/); an RNOR prime (a real-word prime that did not overlap with the target in either the segmental or tonal proportion of the target, e.g., /pie3/-/lun4/); a PSR prime (a pseudo-word that only shared the same segmental structure with the real-word target, e.g., */lun3/-/lun4/); and a PNOR prime (a pseudo-word that had no phonological overlap with the target, */tai3/-/lun4/). The RNOR primes and the PNOR primes served as the baseline conditions to observe the priming effects in the two priming conditions with real-word primes (RSTR, RSR) and the priming condition with pseudo-word primes (PSR).

For pseudo-word targets, the five types of primes were: 1) a PSTP prime (a pseudo-word having the identical word form as the target, e.g., */zen2/-*/zen2/); 2) a PSP prime (a pseudo-word with the same segment but different tone than the target, e.g. */zen1/-*/zen2/); a PNOP prime (a pseudo-word that was unrelated to the target, e.g., /rui1/-*/zen2/); RSP prime (a real word that shared the segmental part with the target, /zen3/-*/zen2/); and an RNOP prime (a real word consisting of no common segment or lexical tone as the target pseudo-word, e.g., /xiu3/-*/zuan2/). The PNOP primes provided a baseline for the priming effects in the two pseudo-word priming conditions (PSTP, PSP), and the RNOP primes served as the baseline for the real word priming condition (RSP) to explore any facilitation or inhibition.

The experimental materials consisted of 333 word forms, 198 of which were used by Lee (2007). The word forms were equally distributed in five lists. 17 word forms were used twice in different lists. All lists had the same targets paired with different primes. The 70 targets were pseudo-randomly divided into 10 subsets (five for the real-word targets and five

for the pseudo-word targets), so that each subset with seven items could take one type of prime in a list. Such materials not only permitted us to examine the lexical and sublexical modulations of tone-word priming, but it also balanced the probabilities of hearing real and pseudo-word forms. See Appendix B for a complete list of word and pseudo-word stimuli. Moreover, the reuse of word forms would not confound our results because no real or pseudo-words within a list appeared more than once except for the repetition priming conditions.

The real word stimuli have no homophones, judged according to the list of Chinese words in the Modern Chinese Frequency Dictionary (Language Teaching Research Centre for Beijing Language Institute, 1986). The average word frequencies of the five types of real-word primes (RSTR, RSR, RNOR, RSP, RNOP) were matched to avoid potential confoundings, supported by a one-way ANOVA revealing no significant difference between the average logarithm frequencies of the five prime types ($F(4, 190) = 0.076, p = .989$). The two words in each priming pair were lexically unrelated. That is, they could not form a disyllabic word.

The materials were produced by a female native Putonghua speaker in a sound proof cabin (Institute of Neuroscience, Newcastle University) with a high-quality Rode NT1-A microphone and E-MU 0404 recording system, digitised at a 16 bit, 44.1 kHz sampling rate on a Dell E5400 laptop via acoustic software programme PRAAT (Boersma & Weenink, 2013). Each word form was pronounced 15 times. Ignoring the first four and the last four recordings, one of the exemplars was carefully chosen. The selection criteria were the following. First, the chosen recording was clearly articulated. Second, the recording had an approximate duration around 550 ms. All experimental materials were normalised for the same duration of 550 ms and intensity of 75 dB SPL with PRAAT, and saved individually per word form.

3.2.3. Procedure

The participants were tested individually in a sound-attenuated room. They sat in front of a laptop (HP 540) with a distance of approximately 80

cm between their eyes and the screen. Auditory stimuli included 70 stimulus pairs, each of which consisted of a prime and a target, presented via a pair of Cosonic CD-778MV headphones at 75 percent of the full volume of the laptop. The presentation of stimuli was pseudo-randomised per participant to ensure that the same type of targets were not presented in more than three successive trials. Participants were randomly assigned to one list and instructed to decide whether the second word form (the target) in a stimulus pair was an existing word in Mandarin Chinese by pressing the button ‘O’ for a positive answer and the button ‘P’ for a negative answer as quickly and accurately as possible. They were also asked to pay close attention to the second word form (the target) in each stimulus pair and to ignore the first word form (the prime, *cf.* Shuai, Li, & Gong, 2012). A practice session with 10 prime-target pairs was administered before the experiment. During the practice session, feedback on reaction time and accuracy was presented on the screen immediately after a judgment was made. A participant was not allowed to proceed to the experimental session until the number of erroneous judgments was equal to or less than three.

A trial began with a set of fixation marks ‘*****’ presented in the centre of the screen for 1000 ms. The prime was delivered 500 ms after the disappearance of the fixation marks, followed by the presentation of the target with an ISI of 250 ms between the prime and the target (Lee, 2007; Sereno & Lee, 2015). For each trial, participants were given a maximum 6 s to make a response. The next trial automatically started as soon as an answer was given. Response latency was measured from the onset of the target (Zwitserlood, 1996; Lee, 2007). Software programme DMDX V4.0.4.6 (Forster & Forster, 2003) was used to control the delivery of auditory stimuli and to record reaction times and accuracy. The entire protocol took about 10 minutes.

3.2.4. Data analysis

Reaction times and accuracy (correct percentage) were the dependent variables. Only correct judgments were included for statistical analyses.

Reaction times shorter than 400 ms and longer than 3000 ms were excluded (Lee, 2007; Shuai et al., 2012). Six participants out of 88 were excluded because they had less than four analysable responses out of seven trials in at least one type of prime-target pairs. In total, 9.2% of the data were rejected in the remaining 82 participants.

One-way repeated measures ANOVAs with the reaction times and correct percentages (accuracy) of real-word targets and pseudo-word targets were performed separately to examine whether Prime-type was a factor leading to systematically varying response patterns for the same targets. Reaction times and correct percentages were averaged both by subject and by item to ensure that the potential priming effects could be generalised rather than determined by some specific items used in our experiment. Greenhouse-Geisser correction was performed when the sphericity assumption was violated. If the Prime-type could be identified as a main effect, planned pair-wise comparisons defined a priori would be performed between a priming condition and the corresponding baseline condition (RSTR vs. RNOP, RSR vs. RNOR, and PSP vs. PNOR for real-word targets). The significance level was set to $p < .05$. All statistical analyses were conducted with SPSS V22 (IBM, Armonk, NY, USA).

3.3. Results

3.3.1. Reaction times

The experimental results of real-word targets paired with five types of primes are displayed in Table 3.1. ANOVAs revealed a reliable main effect of Prime-type (by subject $F(4, 324) = 12.73, p < .001$; by item $F(4, 136) = 10.37, p < .001$). Planned comparisons showed that the average reaction time of the targets preceded by the RSTR primes was 104 ms faster than that in the RNOR baseline condition (by subject $t(81) = -4.80, p < .001$; by item $t(34) = -4.91, p < .001$), and the mean reaction time of the targets primed by pseudo-words with segmental overlaps was 93 ms faster than the PNOR baseline condition (by subject $t(81) = -5.12, p < .001$; by item $t(34) = -3.28, p = .002$). However, the difference between RSR

primes and RNOR primes was not significant (by subject $t(81) = -0.48$, $p = .631$; by item $t(34) = -0.601$, $p = .552$). These results suggest that tone word targets can be facilitated by word primes with identical forms and pseudo-word primes with minimal tone contrasts. In line with Lee (2007), there were no clear priming effects in word targets primed with tonally contrasted real words. These priming patterns (see Figure 3.1) are in line with our predictions based on previous studies and the idea of lexical interference.

Table 3.1 Results of conditions with real-word targets (RT = reaction time, CP = correct percentage).

	Example		Results	
	Prime	Target	RT (<i>SD</i>)	CP % (<i>SD</i>)
RSTR	/lun4/	/lun4/	1078 (266)	92.9 (11.7)
RSR	/lun2/	/lun4/	1173 (215)	89.4 (13.6)
RNOR	/pie3/	/lun4/	1182 (215)	87.1 (13.2)
PSR	*/lun3/	/lun4/	1092 (196)	93.4 (9.6)
PNOR	*/tai3/	/lun4/	1185 (230)	86.9 (12.9)

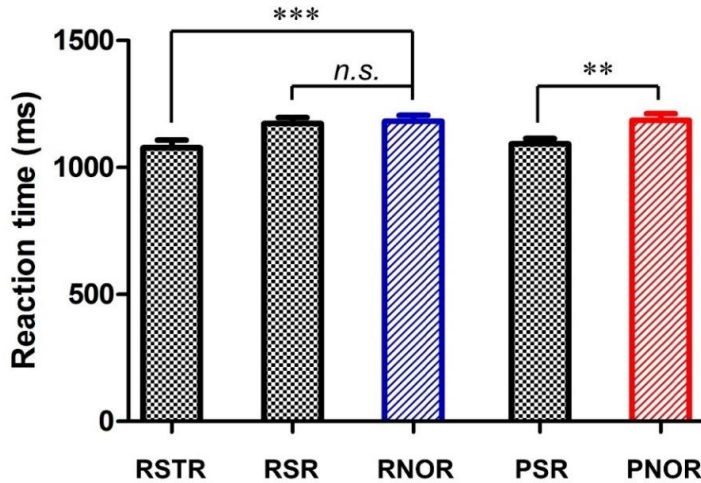


Figure 3.1 Average reaction times in the real-word targets preceded by the five conditions. The baseline condition is coloured in blue for the real-word priming condition; the red bar is the baseline for the pseudo-word-priming condition. *n.s.* $p > .05$, $** p < .01$, $*** p < .001$.

For the pseudo-word targets, the experimental results are shown in Table 3.2. ANOVAs revealed a main effect of Prime-type (by subject $F(4, 324) = 9.01, p < .001$; by item $F(4, 81) = 7.00, p < .001$). Pair-wise comparisons showed that the recognition of tonal pseudo-word forms was facilitated for 59 ms by the identical pseudo-word primes (PSTP vs. PNOP: by subject $t(81) = -2.40, p = .019$; by item $t(34) = -2.49, p = .018$). However, the reaction latency became 88 ms longer when the pseudo-word targets were preceded by pseudo-word primes contrasting only in tones (PSP vs. PNOP: by subject $t(81) = 4.35, p < .001$; by item $t(34) = 2.44, p = .020$). Moreover, the effects induced by RSP primes (real-word primes with minimal tone contrasts) was unclear because no significant difference was identified between the RSP priming condition and the RNOP baseline condition (by subject $t(81) = 0.46, p = .644$; by item $t(34)$

= -0.05, $p = .963$). These results, as illustrated in Figure 3.2, suggest that the processing of pseudo-word targets is inhibited by the presence of pseudo-word primes contrasting in tones. No clear priming effects are produced by real-word primes sharing the same segments with pseudo-word targets. Both of these findings contradict our predictions that lexical decisions on pseudo-words can be facilitated by both real word and pseudo-word primes with minimal tone contrasts.

Table 3.2 Results of conditions with pseudo-word targets (RT = reaction time, CP = correct percentage).

	Example		Results	
	Prime	Target	RT (<i>SD</i>)	CP % (<i>SD</i>)
PSTP	*/dei2/	*/dei2/	1194 (300)	92 (10.8)
PSP	*/dei4/	*/dei2/	1341 (299)	89.2 (13)
PNOP	*/mu1/	*/dei2/	1253 (267)	91.3 (12)
RSP	/dei3/	*/dei2/	1314 (336)	93 (10.3)
RNOP	/leng4/	*/dei2/	1299 (327)	94.4 (10.7)

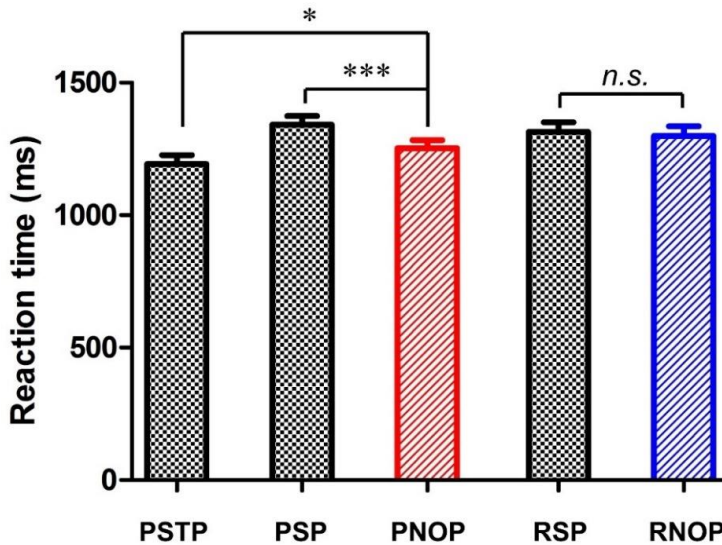


Figure 3.2 Average reaction times in the pseudo-word targets preceded by the five types of primes. The red bar is the baseline for the pseudo-word priming condition; the blue bar is the baseline for the real-word priming condition; n.s. $p > .05$, * $p < .05$, *** $p < .001$.

3.3.2. Correct percentages

The arcsine square root means of the percentage of correct items (Howard, Nickels, Coltheart, & Cole-Virtue, 2006; Ahrens, Cox, & Budhwar, 1990) were used for the same analysis procedures as those with reaction times. For real-word targets, ANOVAs identified a main effect of Prime-type (by subject $F(4, 324) = 6.05, p < .001$; by item $F(4, 136) = 3.21, p = .015$). Planned comparisons showed that RSTR primes and PSR primes led to higher correct percentages than identical primes (RSTR vs. RNOR: by subject $t(81) = 3.68, p < .001$; by item $t(34) = 2.27, p = .030$. PSR vs. RNOR: by subject $t(81) = 3.76, p < .001$; by item $t(34) = 2.55, p = .015$).

However, targets primed by real words contrasting in tones did not induce changes in accuracy (RSR vs. RNOR: by subject $t(81) = 1.42, p = .160$; by item $t(34) = 0.719, p = .477$). These results suggest that when real words are primed by identical real words or by pseudo-words with the same segments, the lexical decision on these real words is facilitated.

For pseudo-word targets, however, Prime-type was a significant main effect in the by-subject analysis ($F(4, 324) = 3.73, p = .006$) but not in the by-item analysis ($F(4, 136) = 1.34, p = .260$). Further pair-wise statistical analyses did not reveal significant differences in the planned comparisons with the correct percentage data averaged by participant (PSTP vs. PNOP: $t(81) = 0.19, p = .849$; PSP vs. PNOP: $t(81) = -1.48, p = .144$; RSP vs. RNOP: $t(81) = -1.32, p = .192$). These results suggest that the accuracy of lexical decisions in pseudo-words is not affected by different types of primes.

3.4. Discussion

The current study aimed to explore how high-level and low-level representations of phonology modulate word recognition in a form priming context. We compared the lexical decision performance in real word and pseudo-word targets preceded by 10 types of primes. The most important finding of our study is that the recognition of real words can be facilitated by pseudo-words with minimal tone contrasts, but there is no clear facilitation when primed by tonally contrasted real words. This finding suggests that the lack of facilitation in minimal tone pairs of real tonal words is a result of lexical interference. That is, real-word targets primed by real words contrasting in tones is affected by both sublexical facilitation and lexical inhibition due to the lexical competition between tonally contrasting word forms (Slowiczek & Hamburger, 1992; Hamburger & Slowiczek, 1996). Moreover, we also found robust inhibition in minimal tone pairs of pseudo-words, and no clear priming effects when pseudo-words are primed by tonally contrasted real words. These results suggest that inhibition is not a specific effect in lexical-level representations, neither is facilitation specifically at the sublexical level.

3.4.1. Form priming in real-word targets

Our results show that the processing of real words is speeded up by identical word primes, but becomes neither faster nor slower when primed by tonally contrasting words. The facilitation in word pairs with formally identical primes and targets is also reflected by the higher correct percentage relative to the baseline condition, whereas the targets in minimal tone-pairs of words do not elicit different error rates compared to the baseline condition. The facilitatory priming effect in identical word pairs is in line with the classic priming pattern in both tonal and non-tonal languages (Zwitserslood, 1996; Lee, 2007; Sereno & Lee, 2015). Together with the lack of facilitation in minimal tone-pairs of real words which are the same Lee (2007), these results attest that our data are comparable with those reported in previous form priming studies (e.g., Lee, 2007; Sereno & Lee, 2015).

Apart from replicating the two form priming effects, the current study revealed evidence of form-based facilitation produced by pseudo-word primes with minimal tone contrasts to the target words (e.g., */lun3/-/lun4/ 'argue'). To the best of our knowledge, this study is the first to investigate sublexical priming with pseudo-words in tone-word recognition. Our finding is similar to some early studies using English materials reporting faster responses to word targets preceded by pseudo-word primes with high phonological similarities (e.g., */blæt/-black, Slowiaczek & Pisoni, 1986; Radeau et al., 1989; Slowiaczek & Hamburger, 1992). The similarity implies that lexical tones are used as segmental cues (i.e., phonemes) during tone-word recognition. Therefore, in the same line of reasoning, we interpret the facilitatory priming effect produced by tonally contrasted pseudo-words in our experiment as evidence that the pre-activation of segment patterns at the sublexical representation level produces form-based priming for the recognition of tone-word targets.

Our findings are consistent with the lexical interference idea which has been used to explain the absence of facilitation in English words primed by real words with a large segmental overlap with their targets (Slowiaczek & Hamburger, 1992). In the current study, in order to judge

the lexical status of target words by accessing the whole-word phonological representation, the cognitive system needs to inhibit the primed word competitors with minimal tone contrasts, even though the overlapping segments produce facilitation at the sublexical level. Consequently, the reaction times only reflect a net effect of the two opposing effects, without showing either overall facilitation or inhibition.

It should be noted that the lack of clear priming effects in minimal tone-pairs of real words can also be explained by the lexical-constraining idea. That is, there are no priming effects because lexical tones are efficient cues constraining lexical selection, so that prime words are treated as completely unrelated words than targets words, as in the baseline condition (Culter & Otake, 1999; Lee, 2007). This idea overlooks the apparent form overlaps in minimal tone-pairs, and predicts no priming effects in any minimal tone pairs. However, in the current study, pseudo-word primes facilitated lexical decisions of real-word targets with minimal tone contrasts. This result clearly shows the existence of form-based facilitation in overlapping segments, and thus endorses the lexical interference account. That is, the lack of facilitation does not mean that there is no facilitatory priming in the processing of target words due to formal overlaps, but the facilitation has been nullified by inhibition at the lexical level of phonological representation.

The lexical interference account also sheds light on some previous studies' findings that primes in minimal tone pairs of real words showed a tendency of facilitation in the processing of targets (e.g., Yip, 2001; Sereno & Lee, 2015). These data can be seen as a reflection of facilitatory priming induced by repeated activation of segmental representations at the sublexical level. However, it is less clear why the priming effect in those studies exhibited relatively stronger form-based facilitation than lexical inhibition. As we pointed out in the Introduction, the potential confounding made the results in different studies not fully comparable. Sereno and Lee (2015), for example, did not control for semantic relatedness between a prime and a target, and thus unexpected semantic priming effects in the baseline might mask the true form-priming effects. Therefore, this issue merits further studies.

3.4.2. Form priming in pseudo-word targets

The priming patterns in pseudo-word targets were largely unexpected. Our original prediction was parsimonious: as long as a prime shares some formal similarity with a pseudo-word target, the processing of this pseudo-word target should be speeded up. However, we only found facilitation in the repetition priming condition with two identical pseudo-words in a stimulus pair. In pseudo-word pairs with minimal tone contrasts, the priming effect is inhibitory rather than facilitatory. Moreover, the processing of pseudo-word targets preceded by real-word primes with minimal tone contrasts do not show clear priming effects relative to the priming baseline comprised of phonologically unrelated words and pseudo-words.

Despite limited knowledge about the priming effects in pseudo-words, explaining these unexpected priming patterns is not impossible. We propose tentative explanations by considering how phonological representations are accessed when a target word form does not have a lexical-level representation as follows. Since a pseudo-word can only access sublexical representations, the processing of pseudo-word targets primed by tonally contrasted pseudo-words must overcome stronger inhibition to access correct representations at the sublexical level. Specifically, the recognition system has to inhibit the primed segments and tones during the perception of a target pseudo-word, when the competition is induced by contrastive tones. As a result, lexical decisions of pseudo-words targets primed by pseudo-words with minimal tone contrasts slow down.

With respect to the absence of clear priming effects in pseudo-words contrasting in tones with real-word primes, we explain this effect as an outcome of two opposing effects on a par with the lexical interference account for the priming effect in minimal tone pairs of real words. Real-word primes access both the lexical and sublexical representations, but pseudo-words with minimal tone contrasts only access the sublexical representations, so the priming effects in pseudo-words can be contributed by two sources. The first source is the inhibitory priming produced by real-

word primes at the sublexical level; the second source is the top-down facilitatory effect from the primed lexical-level representations on the processing of the segmental part of pseudo-words at the sublexical level. Consequently, the two effects counterbalance each other, leading to no prominent priming effects of either facilitation or inhibition.

3.4.3. Theoretical implications

Our study has two major theoretical implications for tone-word recognition. First, representations of segment patterns are at the sublexical level in the mental representation of Mandarin Chinese. Some previous studies have suggested that, similar to non-tone languages, lexical- and sublexical-level phonological representations in tone words of languages like Mandarin Chinese are also organised in a connectionist manner, which allows inhibitory connections within a level but excitatory links between two levels (McClelland & Elman, 1986; Slowiaczek & Hamburger, 1992; Zhao et al., 2011). Moreover, the between-level connections have been defined to be bi-directional, allowing bottom-up and top-down influences in parallel (see McClelland & Elman, 1986 for TRACE model based on English data; see Zhao et al., 2011, Malins, 2013 for recent revised TRACE models for Mandarin word recognition). Our study shows that, for Mandarin Chinese, a legal segment pattern is not a guarantee to access lexical-level representations. It is only a lexicalised combination of a segment pattern and a tone that can induce word responses. It can be further inferred that the sublexical level not only hosts representations of lexical tones, consonants (i.e., onsets) and vowels (i.e., rimes), but also encompasses segment patterns based on lower-order representations of segmental features (i.e., consonants and vowels).

Second, unlike the view that inhibition is induced by lexical competition and facilitation is form-based, the current study suggests that inhibitory priming is not a lexical-level specific phenomenon, nor is facilitatory priming only based on overlapping sublexical features. Although the traditional view can sufficiently explain the results in real-word targets, the unpredicted priming patterns in pseudo-word targets

suggest that inhibition is not necessarily a specific lexical-level effect, and facilitation can also be induced by primed lexical-level representations. If facilitation and inhibition are level-specific priming effects, facilitatory priming should be the only effect in lexical decisions on pseudo-word targets preceded by real words or pseudo-words with minimal tone contrasts. However, our results show that the reaction times of pseudo-word targets in minimal tone pairs of pseudo-words are slower than the baseline, but real-word primes produce some facilitation in the recognition of pseudo-word targets with tone contrasts, leading to no clear priming effects. Therefore, updated theories are needed to explain the form priming in the recognition of tonal word forms.

We propose a general mechanism within a connectionist framework to explain the form priming in tone words. In a connectionist model, it is unnecessary to assume inhibition and facilitation to be level-specific, but is possible to associate the two priming effects with operations at lexical and sublexical representations via excitatory and inhibitory connections. Our basic assumptions are the following. First, in line with existing models, the phonological knowledge of spoken tone words are represented in a two-level structure: lexical and sublexical levels. The units within one level are linked by inhibitory connections, whereas the interconnections between the two levels are excitatory. Such representational organisation allows bi-directional information flow and instant feedforward and feedback communication across levels. Second, we assume that spoken real words can access both lexical and sublexical representations, whereas pseudo-words only have access to sublexical representations.

This mechanism of form priming can account for the priming patterns in the current study. More specifically, in minimal tone pairs consisting of pseudo-word primes and real-word targets, pseudo-word primes facilitate the segmental processing in real-word targets at the sublexical level, producing bottom-up facilitatory priming. The inhibition in tonally contrasting pseudo-word primes and targets is induced by competition at the sublexical level. The lack of evident priming effects in lexical decisions of real and pseudo-word targets preceded by tonally contrasting real-word primes is a net effect of the two opposite priming effects,

namely facilitatory and inhibitory priming. For real-word targets, competition-induced inhibition is at the lexical level, and form-based facilitation is at the sublexical level. For pseudo-word targets, inhibition is at the sublexical level due to the competition between the primes and targets carrying identical segments with different tones, and facilitation is produced by the primed lexical-level representation via the top-down excitatory connections between lexical and sublexical representations. However, it merits future studies to examine whether our observations have task specificity or language specificity.

3.5. Conclusion

Our study investigated how lexical and sublexical representations modulate form priming patterns in words and pseudo-words derived from Mandarin Chinese during a lexical decision task. The main results were that pseudo-word primes could facilitate the processing of real-word targets with identical segments, but inhibit the recognition of pseudo-words with minimal tone pairs. Moreover, no prominent priming effects were revealed in real-word targets and pseudo-word targets primed by real words with minimal tone contrasts. These results suggest that the lack of priming effects may be an outcome of a net effect between facilitatory priming and inhibitory priming. Our finding indicates that inhibitory and facilitatory priming can be general mechanisms for Mandarin word recognition via access to phonological representations at the lexical and sublexical levels, but not specific for lexical competition and form-based sublexical processing respectively.

